



**IFM-GEOMAR**

Leibniz-Institut für Meereswissenschaften  
an der Universität Kiel



# **IFM-GEOMAR Report 2002-2004**

**From the Seafloor to the Atmosphere**

**- Marine Sciences at IFM-GEOMAR Kiel -**



**June 2005**



## Preface

For the first time, the Leibniz Institute of

Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.



#### 3.4 Physical Controls on Oceanic Biogeochemical Cycling

The ocean plays a major role in shaping the Earth's climate, not only because it covers more than 70% of the surface of our planet, but also because of the special properties of sea water and the ocean's physical and biogeochemical dynamics. Its special chemical properties allow today's ocean to contain about 50 times more carbon dioxide ( $\text{CO}_2$ ) than the atmosphere. While these capacities alone already enable the ocean to passively buffer fluctuations in heat- and  $\text{CO}_2$ -content of the atmosphere, the ocean is, in fact, a more active player in the global climate system: By moving water around and depriving large water masses of direct atmospheric contact for seasons to centuries, the ocean circulation takes up heat and  $\text{CO}_2$  from the atmosphere and releases both again later in time and elsewhere in space.

In addition to the "physical (or solubility) pump" which results from  $\text{CO}_2$  being more soluble in colder (and denser) surface waters that may sink to form deep waters, marine biology plays a major role in redistributing carbon in the global climate system. By forming carbon-containing particles that sink through the water instead of moving with it, the "biological pump" contributes to the observed gradient in  $\text{CO}_2$  concentration between the sea surface and the deep waters and, eventually, allows for burial of carbon in sediments at the sea floor and thus removal from the ocean. Both physical and biological pumps ensure that average  $\text{CO}_2$  concentrations in the ocean interior are much larger than those of surface waters. Without the biological activity surface concentrations of dissolved inorganic carbon would be much higher, resulting in approximately doubled concentrations of atmospheric  $\text{CO}_2$ .

A quantitative and comprehensive understanding of what controls the air-sea carbon exchange and the fixation of organic carbon and its removal from the surface layers is essential if we aim to better understand past climate changes and predict the consequences of rising levels of anthropogenic  $\text{CO}_2$  in the atmosphere. Physical controls of the biological pump come into play for the simultaneous requirement of both light and nutrients for phytoplankton growth, since the light-lit upper ocean would be rapidly depleted of essential nutrients with-

out the action of physical transport processes. Vertical mixing also determines the exposure of individual phytoplankton cells to different light levels. This is particularly relevant at mid and high latitudes where deep winter mixed layers may not allow phytoplankton to remain at levels with sufficient light long enough for net growth to take place. Static stabilization of the warming surface layer in spring can then give rise to sudden algal blooms.

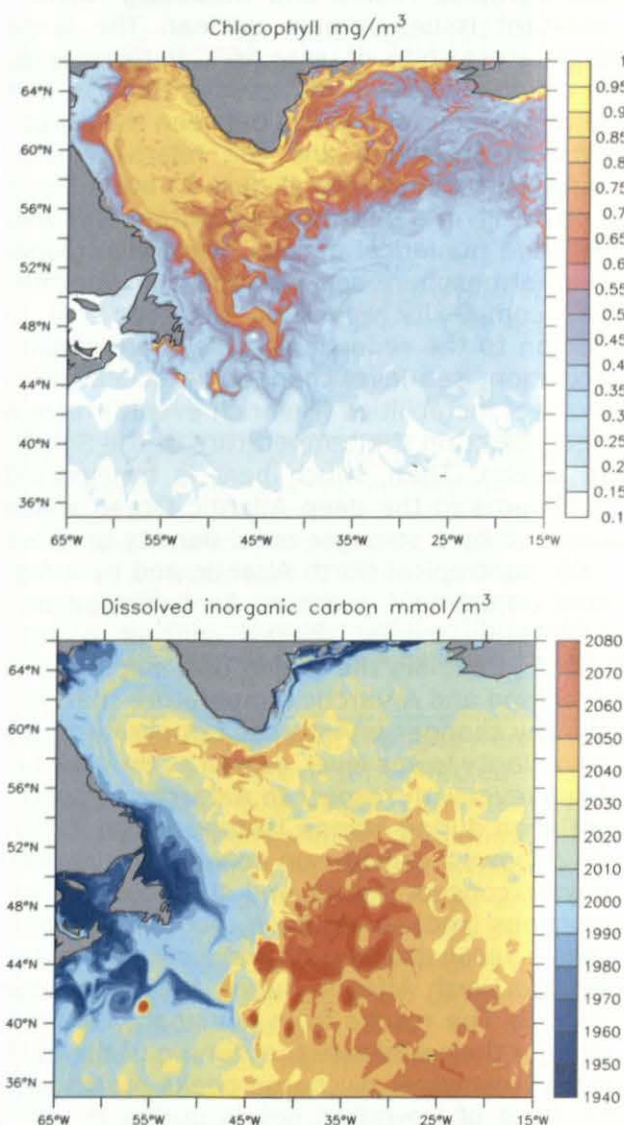


Figure 1: Instantaneous surface chlorophyll concentration (upper panel) and sea surface dissolved inorganic carbon concentration in summer in a coupled model simulation with high horizontal resolution (ca. 5km grid spacing).



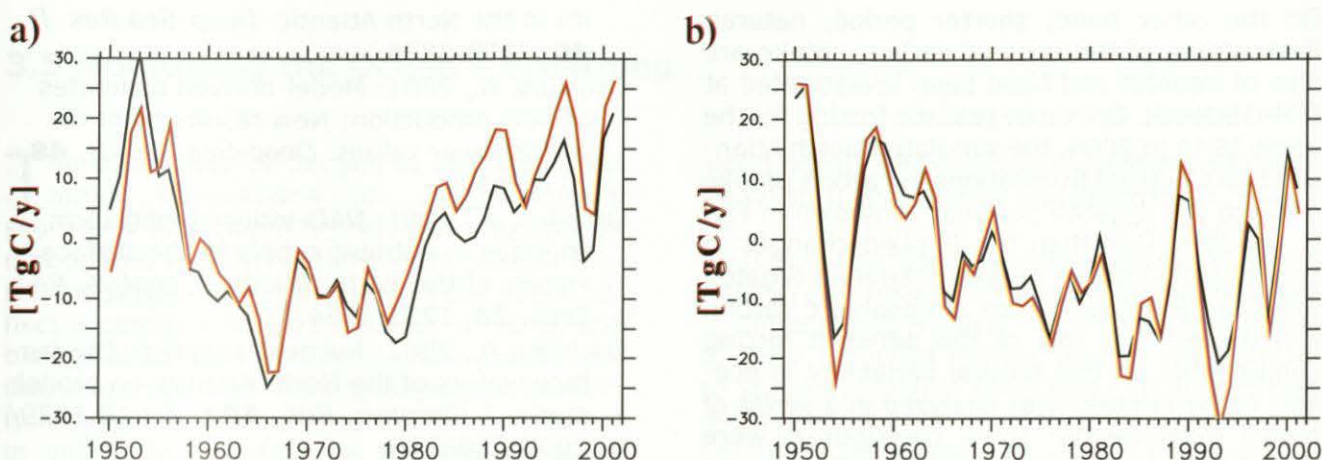


Figure 2 a): Air-sea carbon flux variability in the subpolar North Atlantic (horizontally integrated uptake between 35°N to 65°N). b): Air-sea carbon flux variability in the subtropical/tropical Atlantic (20°S to 35°N). The black line denotes in both figures results from an experiment driven by heat and wind (acting on the ocean) variability only and the red line an experiment driven by the full variability in heat, wind acting on both the ocean and the carbon surface flux formulation, sea level pressure and shortwave radiation. Positive values denote flux into the ocean.

Much of the presently observed temporal and spatial patterns of biological properties can be directly related to these underlying physical controls. For example, satellite observations reveal high concentrations of surface chlorophyll associated with deep winter mixing in subpolar regions and with upwelling off West Africa, America and along the equator, whereas chlorophyll concentrations are lowest in regions where the wind generates downwelling and winter mixing is shallow (the "subtropical gyres"). At present, it is not clear how robust this picture will be under a changing climate. As current patterns, mixing rates, and rates of water mass formation may change under natural and expected anthropogenic climate changes, physical-biological feedback mechanisms in the climate system are likely. It is one aim of the modelling studies initiated at IFM-GEOMAR to help identifying and quantifying the mechanisms by which the ocean physics can control marine biogeochemical cycles and to address their climate sensitivity and the potential participation in global feedback mechanisms.

A particular aim of the modelling activity is to better understand the physical mechanisms controlling the supply of nutrients to the upper ocean and thereby constraining biological production and associated downward carbon fluxes. Using different numerical models of the North Atlantic Ocean with moderate to very high spatial resolution coupled to a nitrate based pelagic ecosystem model, the contribution of oceanic mesoscale eddies in fueling biological production could be quantified and

was found to account for up to 30% of the total biological production along the margins of the subtropical gyres. Another finding was that double diffusion, which is caused by different molecular diffusivities of salt and heat and has not been considered previously in the context of basin-scale nutrient budgets, enhances nutrient supply in the subtropics by an amount similar to that of the mesoscale eddies.

Using a constant ratio between carbon and nutrients for the buildup and disposal of organic matter in the ecosystem model, the same coupled models were used to show that the physical environment indeed strongly controls the physical and biological carbon pump of the North Atlantic. For instance, numerical models with an improved representation of the observed circulation and frontal structures, for example the Gulf Stream position and the Northwest Corner of the North Atlantic Current as shown in Figure 1, show a significant increase (up to 25%) in carbon uptake from the atmosphere compared to models with lower resolution and less realistic representation of these regions. It was demonstrated that such an improved simulation can be achieved both by increased resolution or by using simple assimilation techniques in coarser models. Similar differences can be expected for simulations of the uptake of anthropogenic CO<sub>2</sub> by the North Atlantic and, in turn, for the uptake of the global ocean, since the subpolar North Atlantic is one of the few locations where the deep ocean is ventilated with the increasing anthropogenic CO<sub>2</sub> concentrations.



### 3. Scientific Highlights

On the other hand, shorter period, natural, fluctuations of the oceanic carbon uptake are also of interest and have been investigated at IFM-GEOMAR. Driven by realistic forcing for the years 1948 to 2004, the simulated North Atlantic shows natural fluctuations in carbon uptake of up to 0.1 Gigaton per year as shown in Fig. 2, which is less than the implied changes in annual global ocean uptake of several Gigaton per year estimated from atmospheric carbon inventories. The role of the different forcing components on this natural variability in oceanic carbon uptake was analyzed in a series of model experiments: Minor contributors were identified to be shortwave radiation driving primary production in the ecosystem model and input of turbulent kinetic energy (potentially) driving mixed layer depth changes. Significant contributors on the order of 10–20% of the total variability in the subpolar North Atlantic are variability in sea level pressure and the near surface wind in the air–sea carbon flux formulation. However, the most significant contributors are wind stress and heat flux driving dynamically and thermodynamically the physical ocean model (Fig. 2).

It was furthermore shown that the fast, barotropic and the delayed, baroclinic response of the North Atlantic circulation to the North Atlantic Oscillation (NAO), which is the dominant mode of atmospheric variability in the North Atlantic sector, has strong impacts on the frontal systems and related nutrient and carbon distribution in the northwest North Atlantic and consequently on changes in carbon uptake. Given a longer term prediction of the NAO, it appears possible to quantify in turn interannual changes of the uptake of atmospheric CO<sub>2</sub>, including its anthropogenic part, by the North Atlantic.

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